EnerVault

Safe, Reliable, Cost-Effective Energy Storage

Megawatt-Hour, Fe-Cr Redox Flow Battery System ARRA Demonstration

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CEC ARRA ES Workshop
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Company Overview

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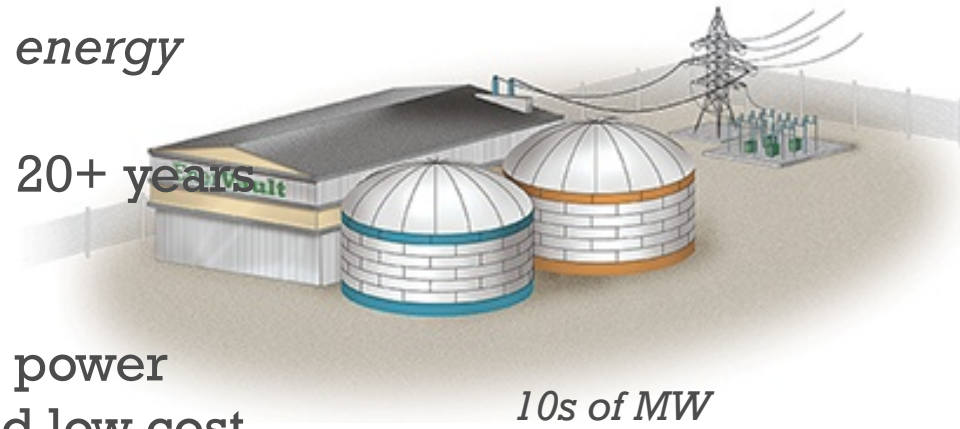
Focus: *True long-duration, grid-scale energy storage…*

Megawatt-hour scale, System life 20+ years



10s of MW
100s of MW-hr

Distinction:

Long duration storage at constant power
Unparalleled safety, reliability, and low cost

Location: Sunnyvale, CA; Founded 2008

Impact of R&D funding

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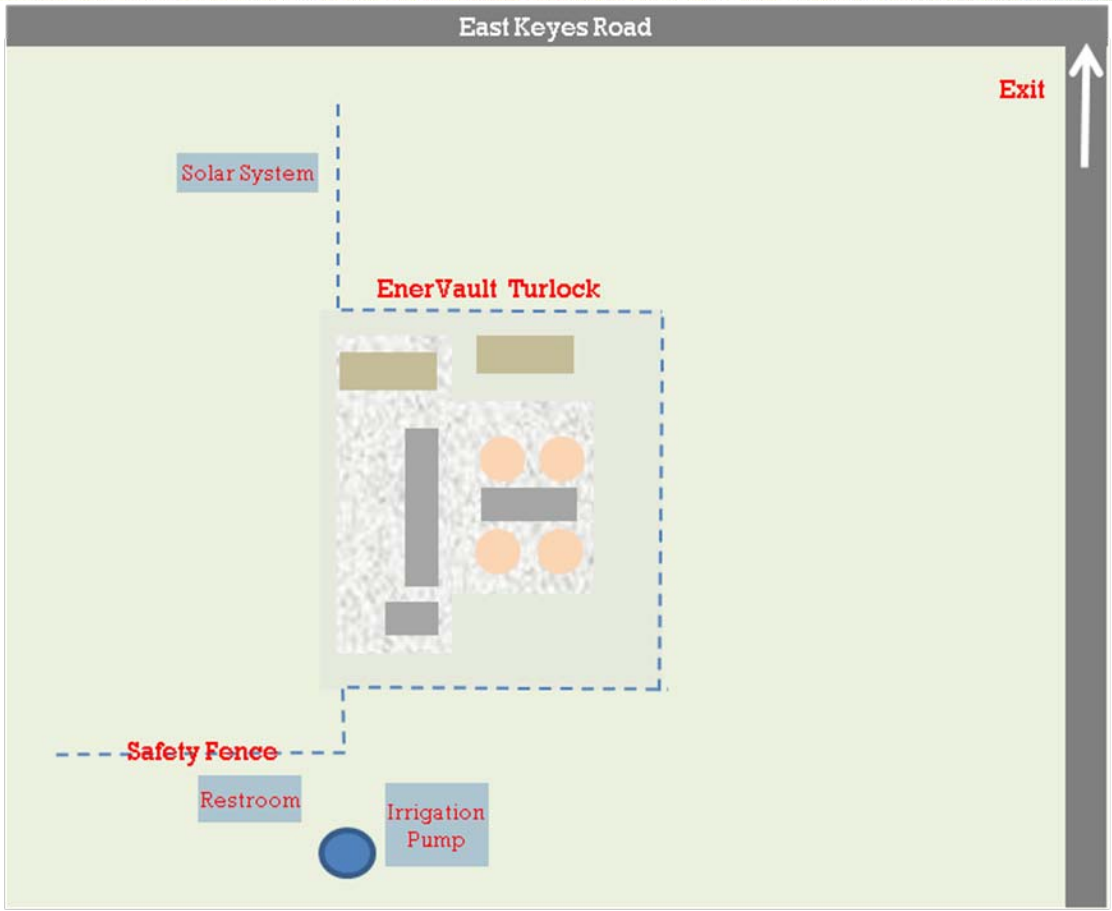
- *Attracted investment: 6X leverage > $30M*
- *Accelerated development significantly*
- *Created market transformative products with the potential to support key policy goals*

- *Provided recognition for credibility in educating broad public*
- *Attracted strategic partnerships to leverage knowledge and resources*



EnerVault Turlock

EnerVault System:

- Technology: Redox Flow Battery
- Chemistry: Iron-Chromium
- Power: 250 kW_{AC}
- Energy: 1 MW-hr / 4 hours duration at full rated power

Solar:

- 150 kW_{AC} PV
- 22 dual-axis trackers, 42 panels each
- 924 solar panels, 200 Wp each
- 2 DC to AC inverters, 75 kW_{AC} each
- Installed in 2008

Load:

- 260 kW groundwater irrigation pump

Connection:

- Common 480 V AC bus
- 21 kV grid connection

EnerVault MW-hr Field Unit

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see highlights at:
http://enervault.com/enervault-turlock-dedication

"Redox flow batteries may hold great potential for replacing gas-fired peaking power plants, and for providing badly needed grid stabilization services."

Peter Kelly-Detwiler, Forbes

Field Demonstration: 250 kW_{AC} / 1 $MW\text{-}hr_{AC}$ System

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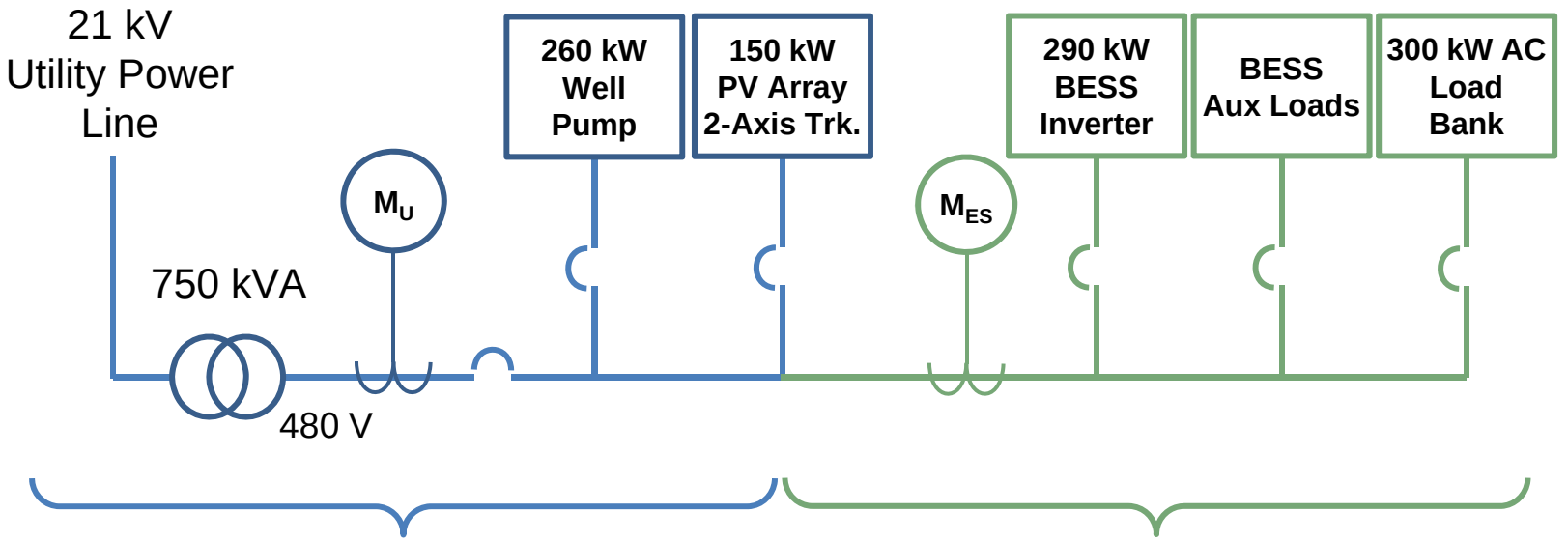
Site Single Line Diagram



Original Site Installation
Well pump plus 2- axis PV; TOU tariff

Addition of Fe-Cr RFB for
Time shifting, peak demand management

Field Demonstration: 250 kW_{AC} / 1 $MW\text{-}hr_{AC}$

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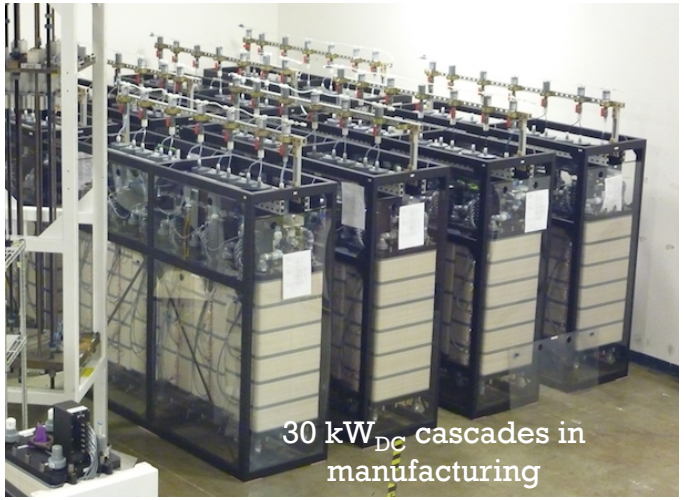
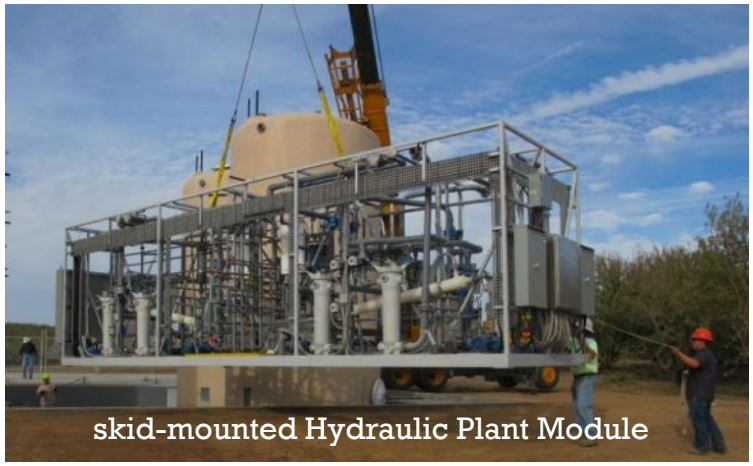
Key System Building Blocks Implemented in the Field


30 kW_{DC} cascades in manufacturing

9 each, 30 kW_{DC} cascades installed


Engineered Cascade™
cascade module


skid-mounted Hydraulic Plant Module


Electrolyte Storage Tanks


Inverter

Design-Build Time Line

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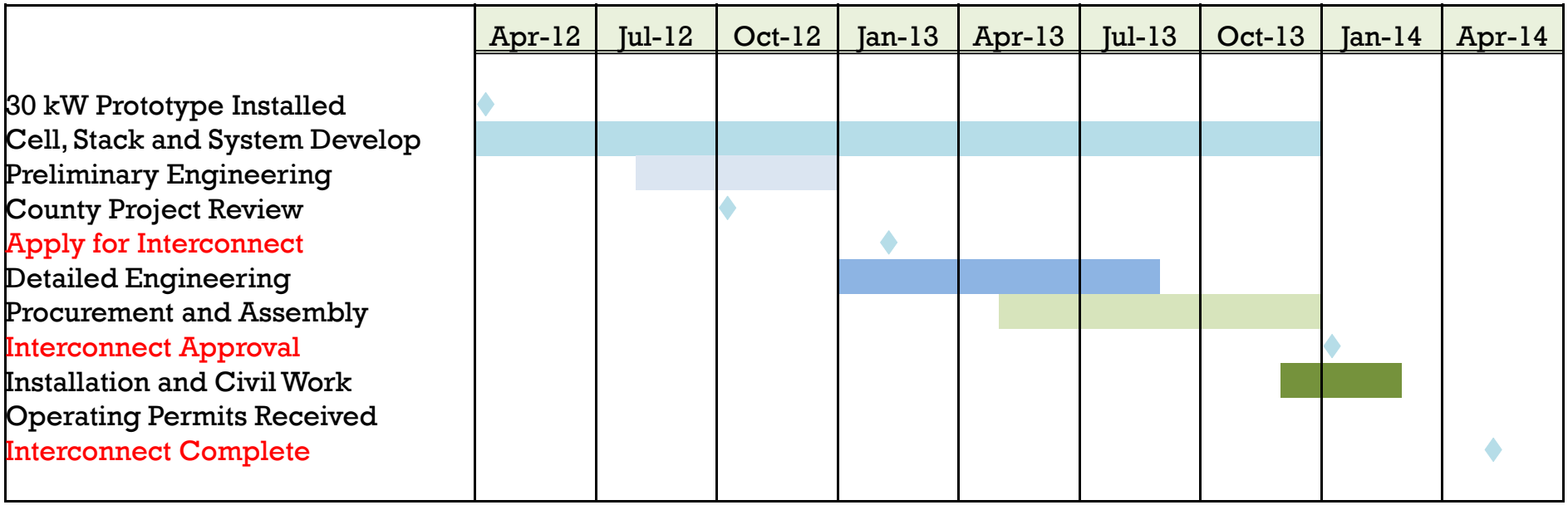
First plant: time line dominated by NRE; concurrent development



- 20-Month Design/Build Project
  - EnerVault scope: system design, specifications, build stacks, integration
  - Partners' scopes: detailed engineering, procurement, assemble, install
- Interconnect: Significant added cost and delay
  - First application February 2013
  - Re-submit September 2013 after complying with PG&E requirements for inverter
  - November 2013, failed initial Rule 21 review due to IOU voltage regulation problems, notified of $170k cost to EnerVault to pay for mitigations of voltage regulation problem
  - January 2014, Approved alternate approach
  - Interconnect completed May 7, 2014

Commissioning and Performance Ramp

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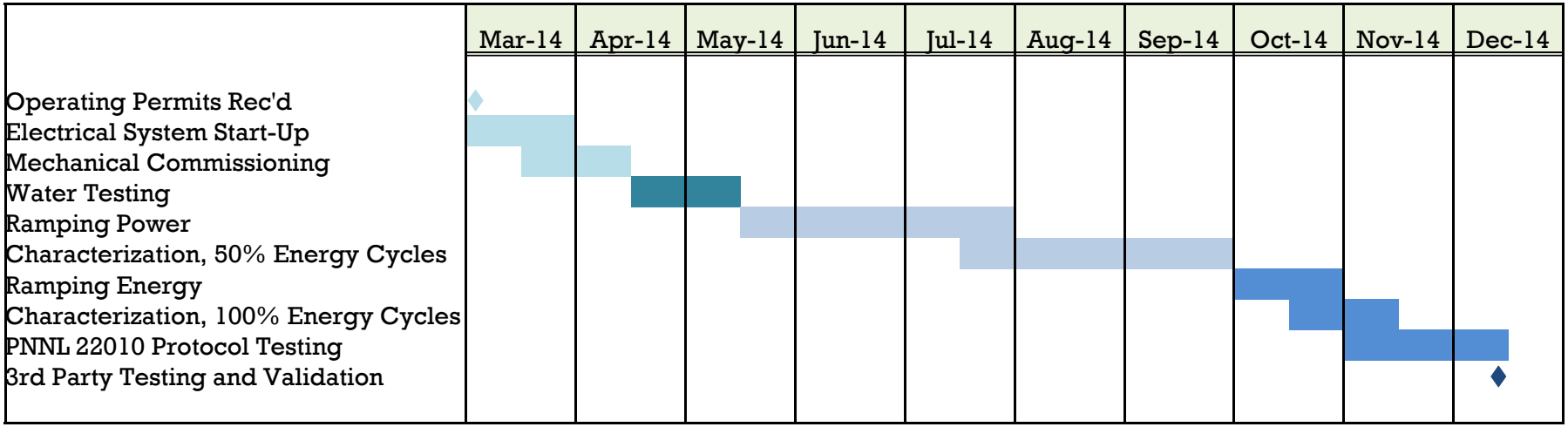
First-ever Fe-Cr plant this scale; new technology – walk before you run!



- Completed commissioning on May 22nd, 2014
- Now ramping system power to target with short fill of electrolyte
  - Facilitates rapid cycle testing to validate system model
  - Determining flow-current-cell voltage relationships
  - Develop high level software, determine interlock settings
- Next: complete electrolyte fill in July and ramp system energy
- Demonstration: certification testing with independent laboratory

Lessons Learned?

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- Early involvement of local authorities is key to smooth permitting
- Shop-fabricated, modular construction for reduced field time/cost
- Utility interconnect: it's new for everybody involved – allow time

How are the Energy Storage Systems Performing

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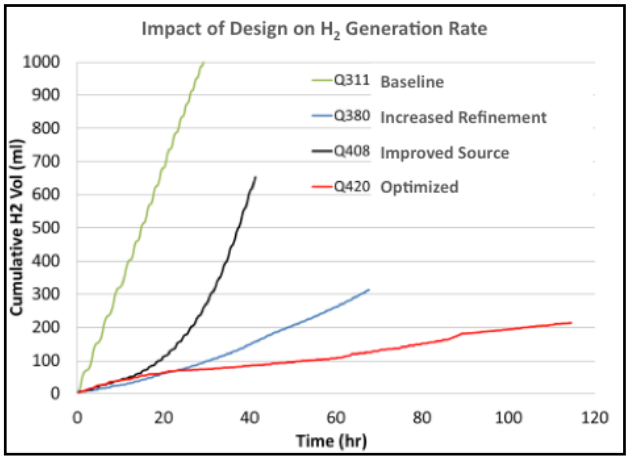
Minimize Side Reactions



>10x reduction in side-reaction rates

2010

2 kW/1 hr Test Unit

10X

2012

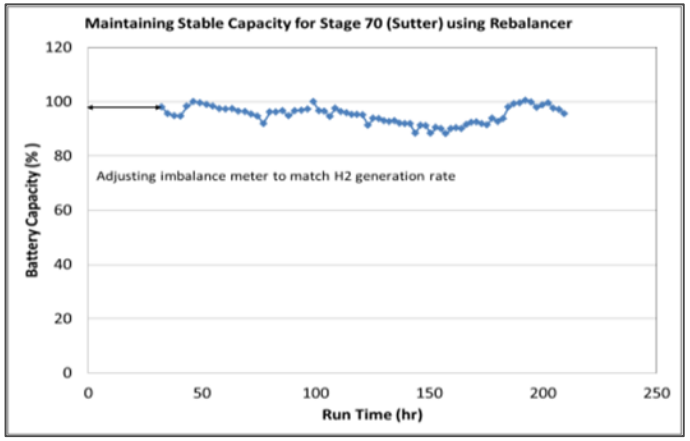
30 kW Pilot System

10X

2014

250 kW_{AC}/1 MW-hr

Dynamic Rebalancing



Automated, on-the-fly capacity stabilization

Certification Testing

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US DOE ESS Performance Measurement Protocol PNNL 22010:

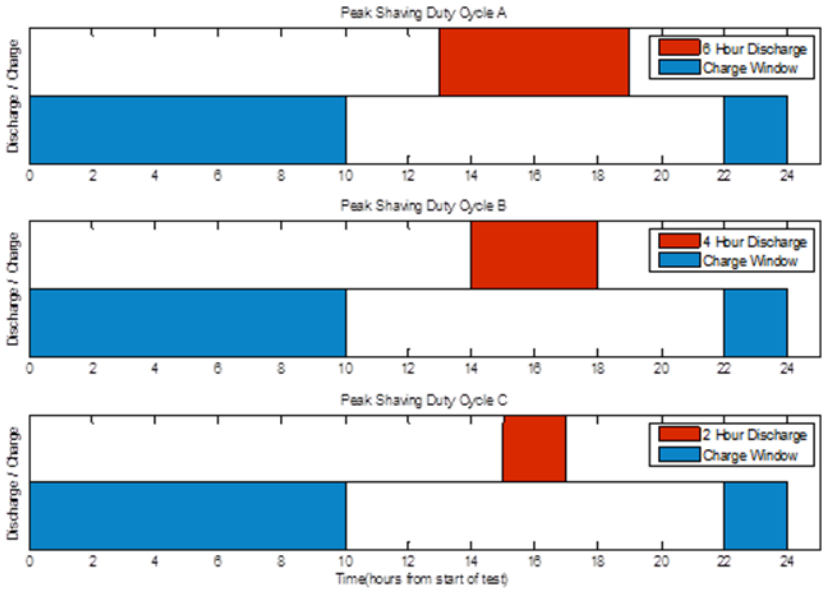

Figure 5.1.3. Peak-Shaving Duty Cycles

- Defined protocols for system energy, efficiency, and ramp rate
  - Clear definition of the system boundaries for efficiency calculation
  - Clearly defined duty cycle and test regimen for multi-cycle performance
- True AC-AC efficiency measured over multiple cycles

Source: US Department of Energy, Protocol for Uniformly Measuring and Expressing Performance of Energy Storage Systems, PNNL 22010, Nov., 2012

Field Demonstration: 250 kW_{AC} / 1 $MW\text{-}hr_{AC}$ System

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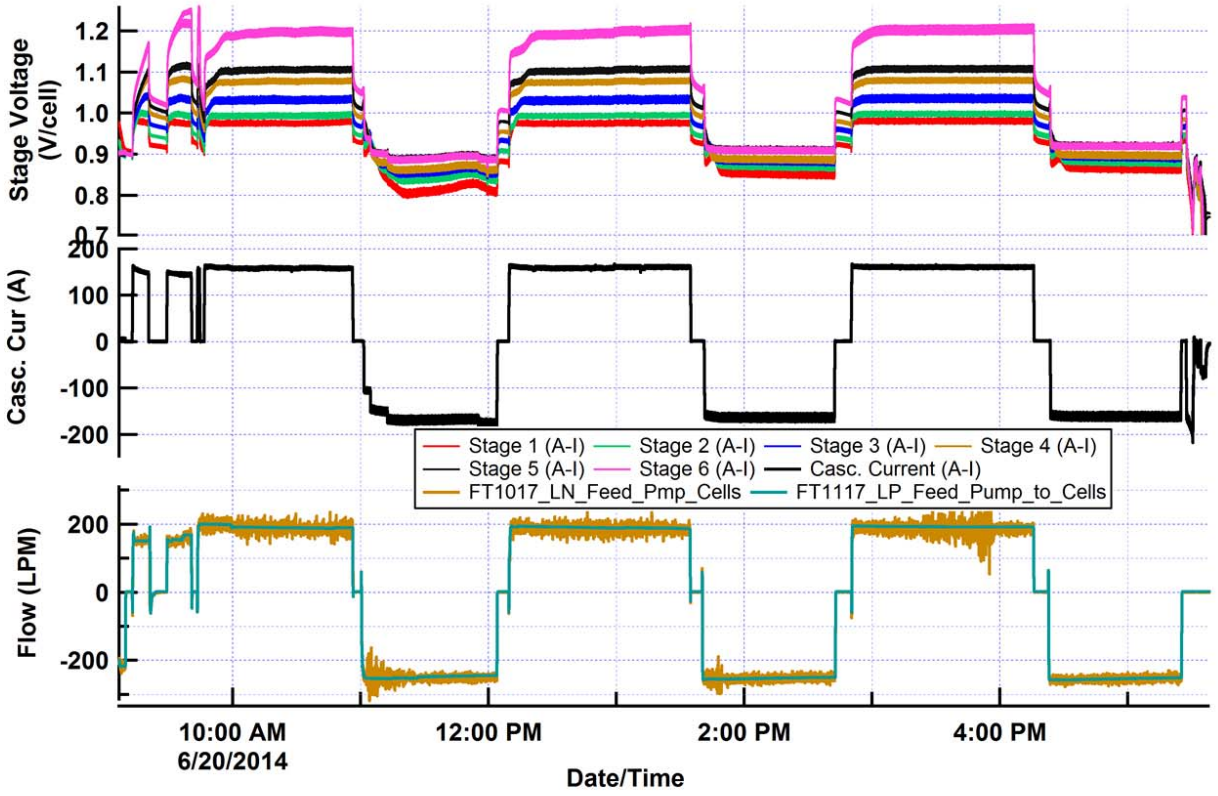
Example 4T Cycle results, 20 June, 2014 – 220 kW – 1 hr

- First cycle used to establish flow-current-voltage targets at 220 kW power
- Subsequent cycles verify stability, validate model
- Short cycles – long enough for steady state; short enough for quick progress



Field Demonstration: 250 kW_{AC} / 1 $MW\text{-}hr_{AC}$ System

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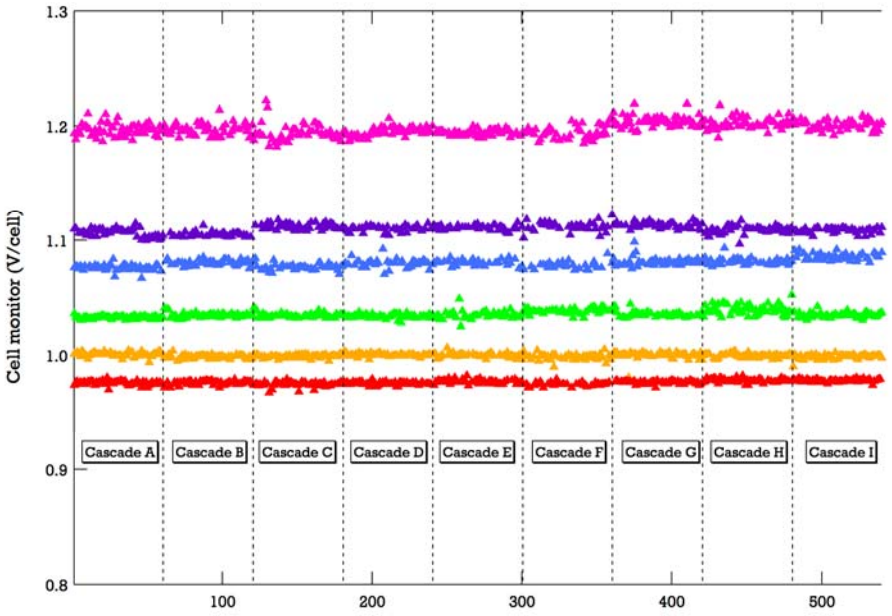
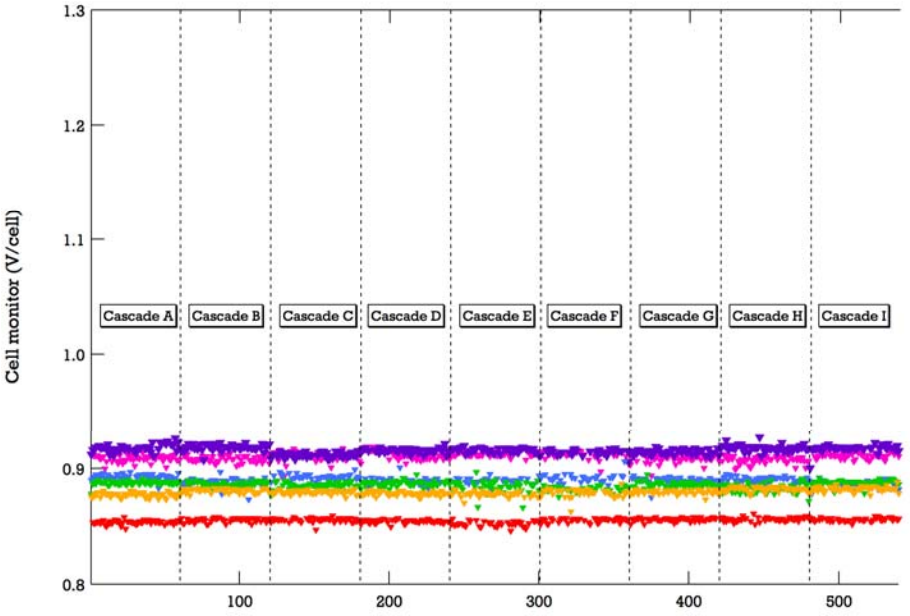
4T Cycle results: Cell Voltage Uniformity – Charge and Discharge Cycles

- Showing Cell voltages by stage in each of nine, 30 kW cascades
- All cells within ~20 mV – excellent cell uniformity; excellent flow uniformity
- Flow and current distribution among stacks is purely passive balancing by design and quality of manufacturing and factory acceptance testing



Charge



Discharge

Constant Power + Low Marginal Energy Cost

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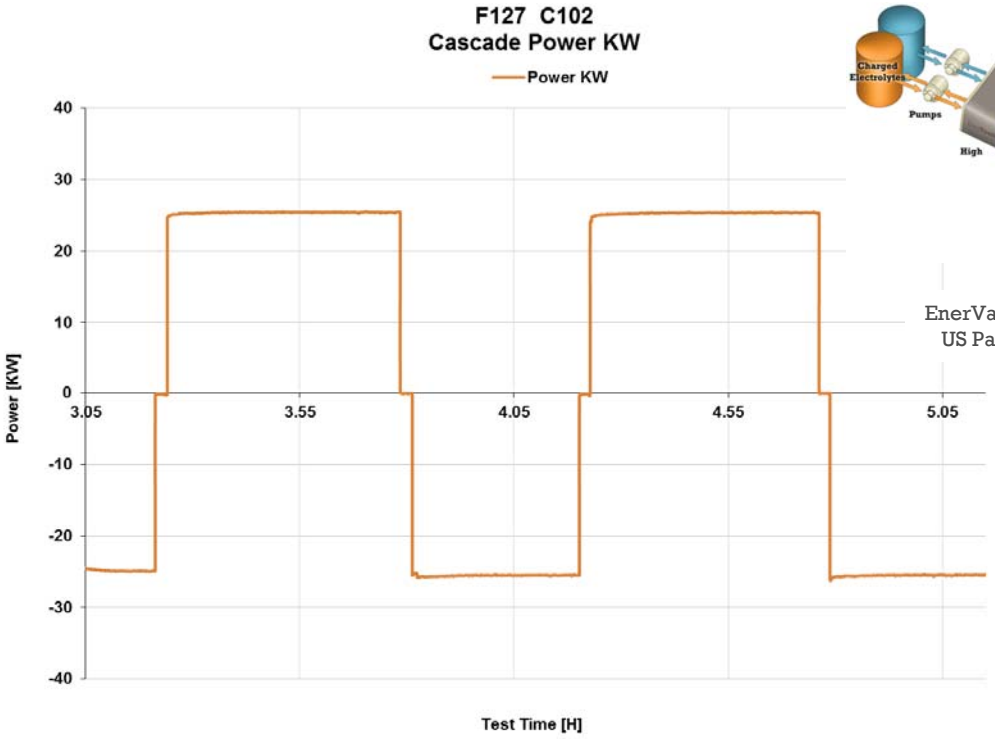
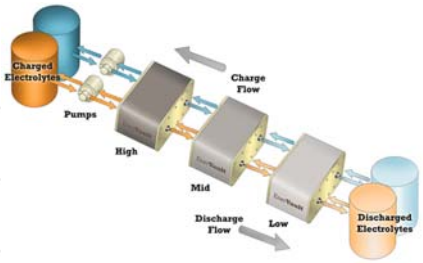
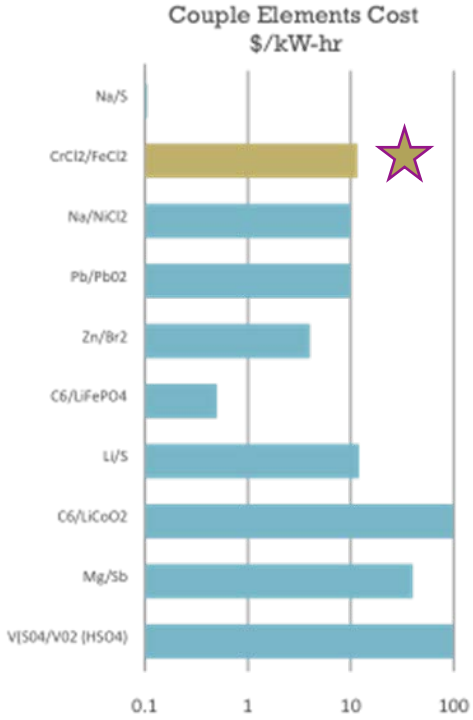
Engineered cascade delivers constant power discharge, rapid switch (seconds) between charge and discharge



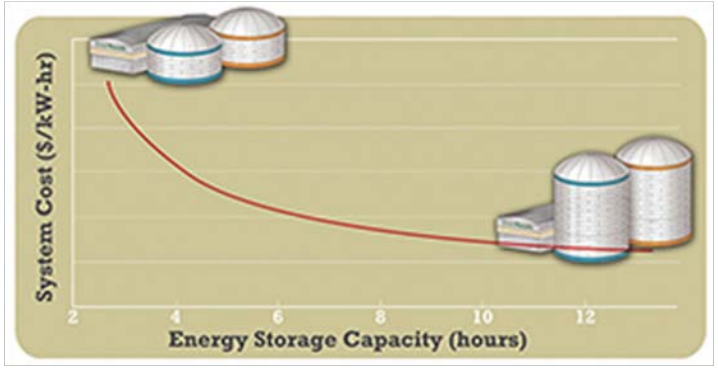


EnerVault's Unique Design
US Patent No. 7,820,321



adapted from: Wadia et al., *J. Power Sources* **196**(2011)1593-1598

- *Enables 6-12 hours of storage in the $250/kW-hr total price range*



EnerVault Turlock – Nov 20-21, 2014

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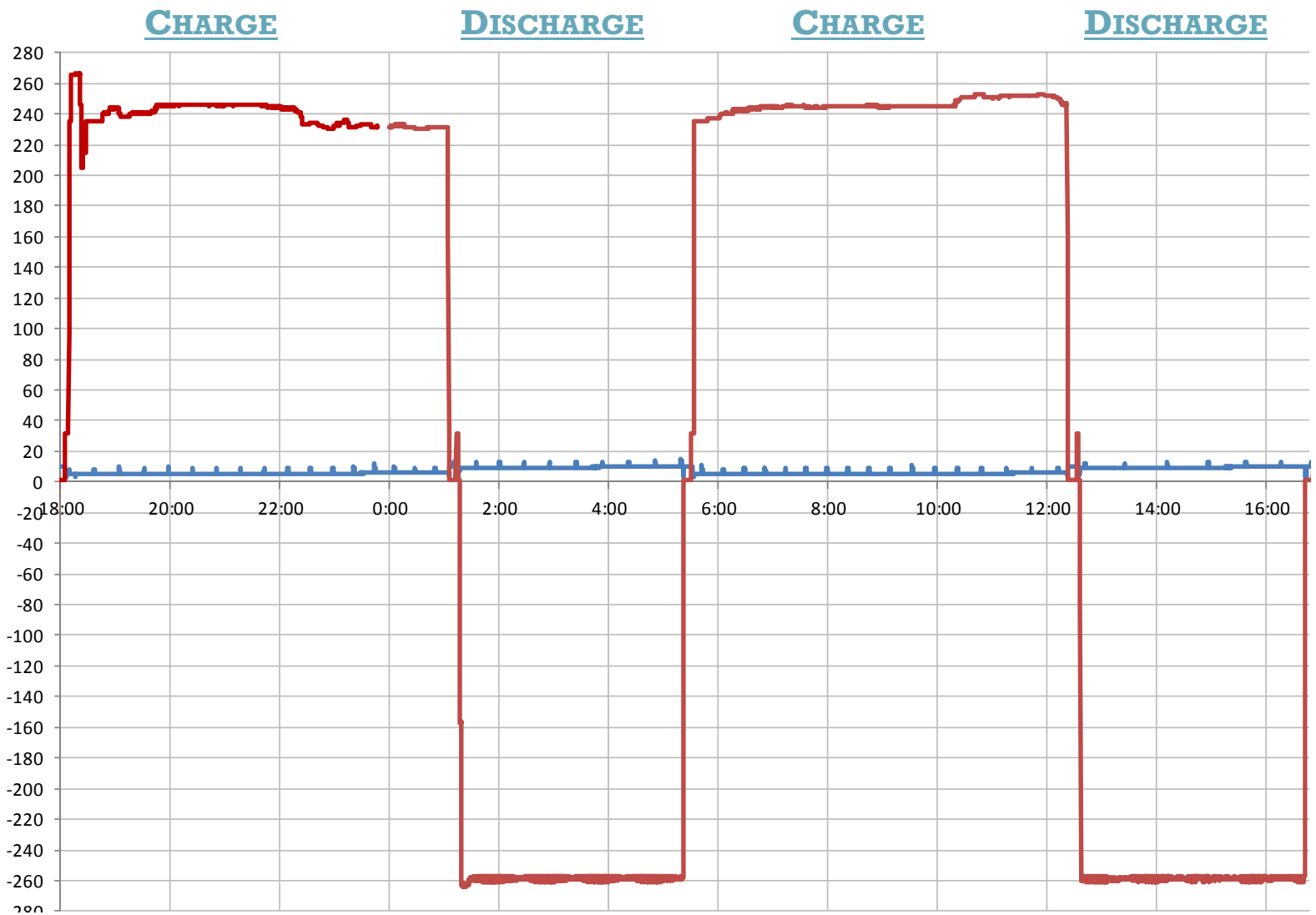

How EnerVault Systems Support the Grid

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Global demand for utility-scale, long duration energy storage has taken off

Organization	Size (Power)/Duration)	Status	Description
	14 GW/6 hours	140,000 MW PHS; 800 MW CAES, NAS, and Flow 250 MW Li-ion, Pb-acid, flywheel	
Terna Rete Elettrica Nazionale	35 MW / 7 hours	Installed NAS	Contract awarded (May 2013)
ほくでん (Hokkaido Electric)	12 MW / 5 hours	Underway	Contract awarded (July 2013)
PG&E	Min 1.5 MW / 4 hours	In Contracting	RPS RFO (Dec 2013) PV+ Storage; 1.9X TOD, penalize intermittency, curtail rights
ieso	50 MW	34 of 50 MW selections announced	RFP issued (March 2014), selections announced (July 2014) to increase wind and solar use
SOUTHERN CALIFORNIA EDISON	50 MW/4 hours	In contract negotiations	RFP issued (October 2013) for local capacity requirements
PSEG LONG ISLAND	150 MW /12 hrs	In short-listing (Mar 2014)	RFP issued (November 2014) post Superstorm Sandy
California ISO Shaping a Renewed Future	Avg 58 MW >2 GW Storage Interconnects	Cluster 7 Applications closed (April 2014)	Interconnect application increased from 0 (cluster 6, 2013) to 36 projects Typical size 25 and 50 MW Average application fee: $105k
conEdison	58 MW / 12 hours	RFI July 2014	12 hour demand reduction beginning 2016
HECO	60 MW / 0.5 hours	RFP July 2014	HECO response to PUC over-ruling capital plan because not solving problems of DG
SDGE	>25 MW / 4 hours	RFP September 2014	To meet Local Capacity Requirements, alternative to CT
Terna Rete Elettrica Nazionale	2MW / 4 hours	RFP Oct 2014	Flow battery demonstration
PG&E SOUTHERN CALIFORNIA EDISON SDGE	PG&E: 80.5 MW / 4 hours SCE: 16 MW / 4 hours SDG&E 16.3 MW / 4 hours	RFP Dec 2014	First procurement for AB 2514, 1325 MW (October 2013), Procurement plan approved July 2014

Drivers for Long Duration Energy Storage

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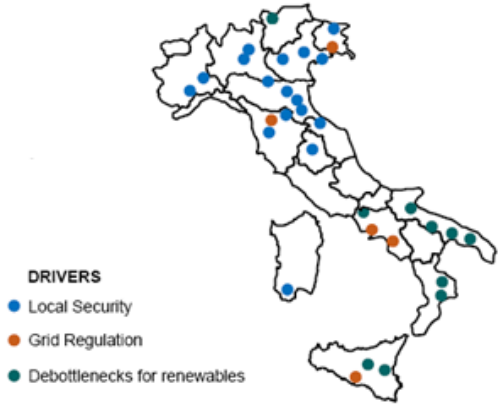
- **New York:** Grid Resilience – Increased storage to avoid black-outs, faster grid recovery
- **Texas and Hawaii:** Flexibility – Enabling high penetration of renewables / avoid curtailment
- **Italy:** Flexibility – Grid congestion relief from high penetration of wind and solar
- **Japan:** Efficiency – 15% peak demand reduction post Fukushima



EnerVault Vision for the Future

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Flexible generating stations providing energy dispatch and absorption

- The EnerVault grid-scale / long-duration energy storage plant
  - Modular power section (stacks + inverters) for low cost, power and energy fit, and system redundancy in the new components
  - Fully leverage economies of scale from chemical process industry in hydraulic modules and storage tank facilities
  - Avoid turning the flow battery into just a large integrated cell

- Extend the life of existing assets, provide grid resiliancy
- Replace combustion turbines for ramp control and peak shaving
- Avoid/delay construction of new transmission lines and gas pipelines

Barriers to New Storage Technology

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From HERE

MW-hr

to HERE

100's of MW-hr

EnerVault Commercialization Timeline

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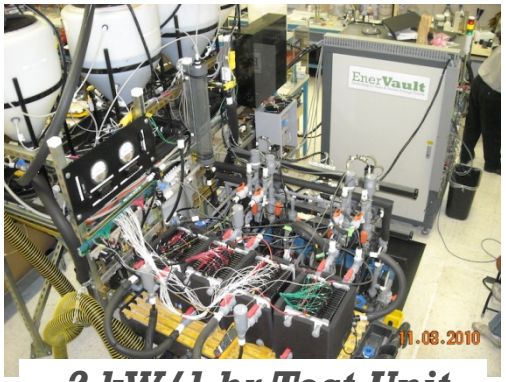
Flexible, Bi-Directional Power Generation Plants



2 kW/1 hr Test Unit

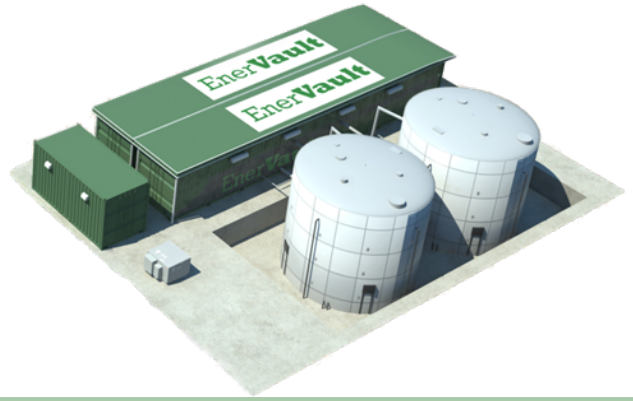
250 kW/1 MW-hr

25 MW / 100 MW-hr

2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017

30 kW Pilot System

2 MW / 12 MW-hr



Barriers to New Storage Technology

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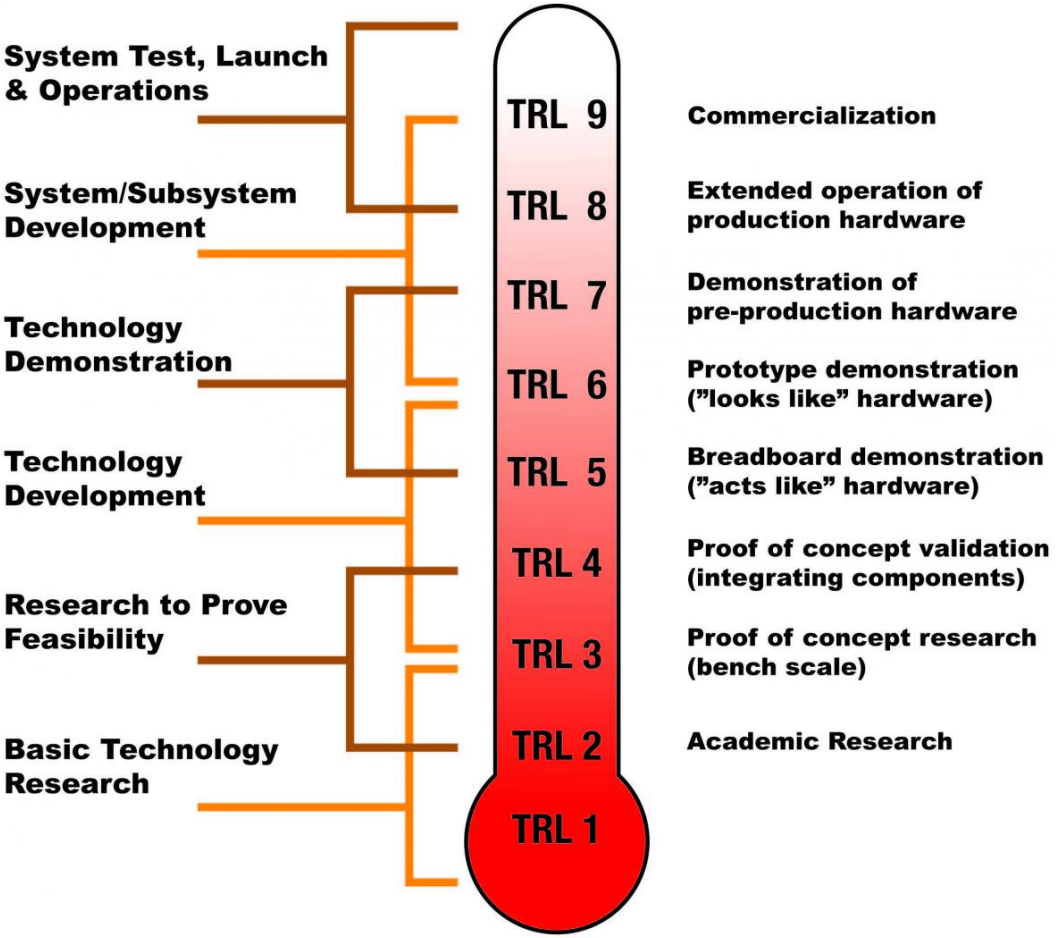
- Many grant opportunities for early technology development (ARPA-E, EPIC, …): Cost $
- ARRA ES program helped EnerVault go from ~TRL 3 to > TRL 5 (System demonstration in a relevant environment): Cost $$
- Very few opportunities to support moving from TRL 5 to > TRL 8: Cost $$$$
  - Need real application including full automation, telemetry, technical and business case demonstration
- Market Transformation mandates like AB 2514 help attract investment, but aren't enough
  - 100% of recent SCE ES is established, known technology used in known application

Technology Readiness Level



Source: NASA - http://www.nasa.gov/sites/default/files/trl.png

Lowering Barriers to New Storage Technology

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Application and Business Case Demos

- Need application demonstrations at IOUs, POUs, IPPs, and RE Farms
  - Demonstrate capability, learn requirements, and demonstrate business case
  - Incentives, mandates, and rate-basing to invest in demonstrated technology, not yet fully commercial

Application	Demo Size	Full Scale	Comment
Flexible Peaker	2-10 MW / 3 hours	50 MW / 150 MW-hrs	100 MW of flexible range
Capacity Peaker	2-10 MW / 4 hours	25-50 MW / 200 MW-hrs	RA
Renewable Sited Storage	2-10 MW / 6 hours	25 MW / 150 MW-hrs	Wind and PV; ToD premium, dispatchable, curtailment avoidance
Hybrid (CT +ES)	2-10 MW / 6 hours	50 MW / 300 MW-hrs	
Transmission Peaker (Congestion Relief)	2-10 MW / 4 hours	50 MW / 200 MW-hrs	
Urban Resiliency	2-10 MW / 12 hours	25 MW / 300 MW-hrs	
Micro Grid	2-10 MW / 12 hours	20 MW / 120 MW-hrs	Islanding + greater renewable use

SUMMARY

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- *How the energy storage system supports the grid;*
- *How the energy storage system is performing;*
- *How R&D funding makes the energy storage project possible;*
- *Identifies lessons learned; and*
- *What barriers is your storage system facing and what is needed to commercialize the energy storage system?*

THANK YOU!

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